Fermilab

Particle Physics Division
Mechanical Department Engineering Note

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Title: Calculations and Discussions of the One side Power Drive for VM Magnet Track Moving System

Author(s): Edward Chi

Reviewer(s):

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Abstract Summary:

To design a power track moving system move 450 tons VM magnet along the beam direction for about 150" in each direction, such system is driven by one side power force only. It is necessary to analysize and to understand the mechanical behavior of the related parts resulting from the unbalance force, especially it is true for the rail anchor bolts.

Applicable Codes:

"Allowable Stress Design", AISC, 9th edition

" Product Technical Guide", HILTI North America, 2002 edition

A Brief Discussion/calculations of the One Side Power Drive Only for the BTeV Vertex Magnet Track-moving System.

Introductions

The BTeV Vertex Magnet (VM) is considering to design a track-moving system to move the 450 tons magnet along the beam direction (+/- Z direction, i.e.: north-south dir. Of the C0 collision hall). Currently, the designated travel distance is about 150".

The VM track-moving system is composed of: Support structures; 4 Hilman rollers with Accu-roll guidance features; Rail system (special steel plates for rail, alignment devices, special anchors and guiding device); Power drive system (actuator, reducer, couplers, motor and control system to generate about 45 tons push/pull force to move the VM along the rail within the designated tolerances (home position with 0.5 mm, skewing angle in plan view (xz plane) is about +/- 0.02 degree). The moving speed will be controlled within 5"/minute in Z direction.

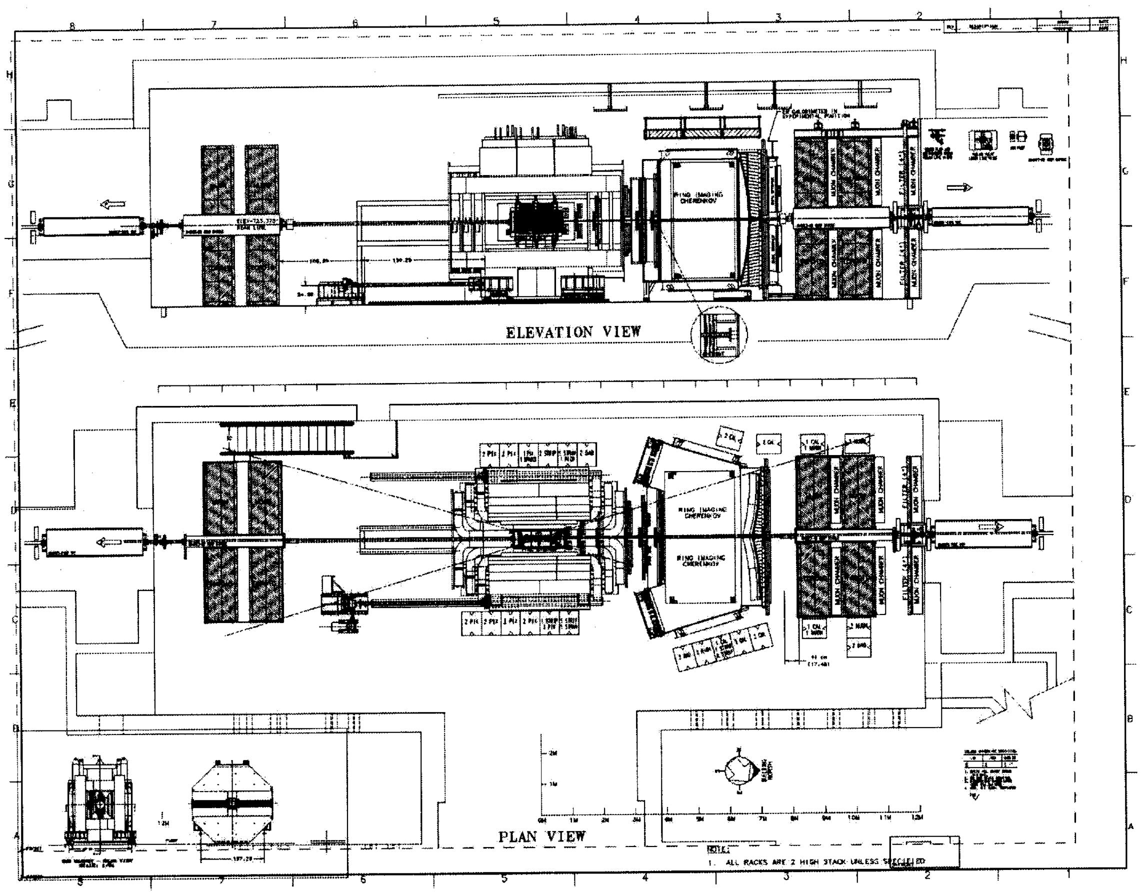

Figure 1: General layout of the BTeV experiment at C0 collision hall
(with one side driving force only for VM track-moving system)

Currently, we're considering to design the VM track-moving system with only one side driving force as showing on figure 1. It is necessary to analysis and to understand the mechanical behavior of some related parts resulting from the additional unbalance force, especially it is true for the rail anchor bolts as showing on figure 2.

Assumptions and Calculations:

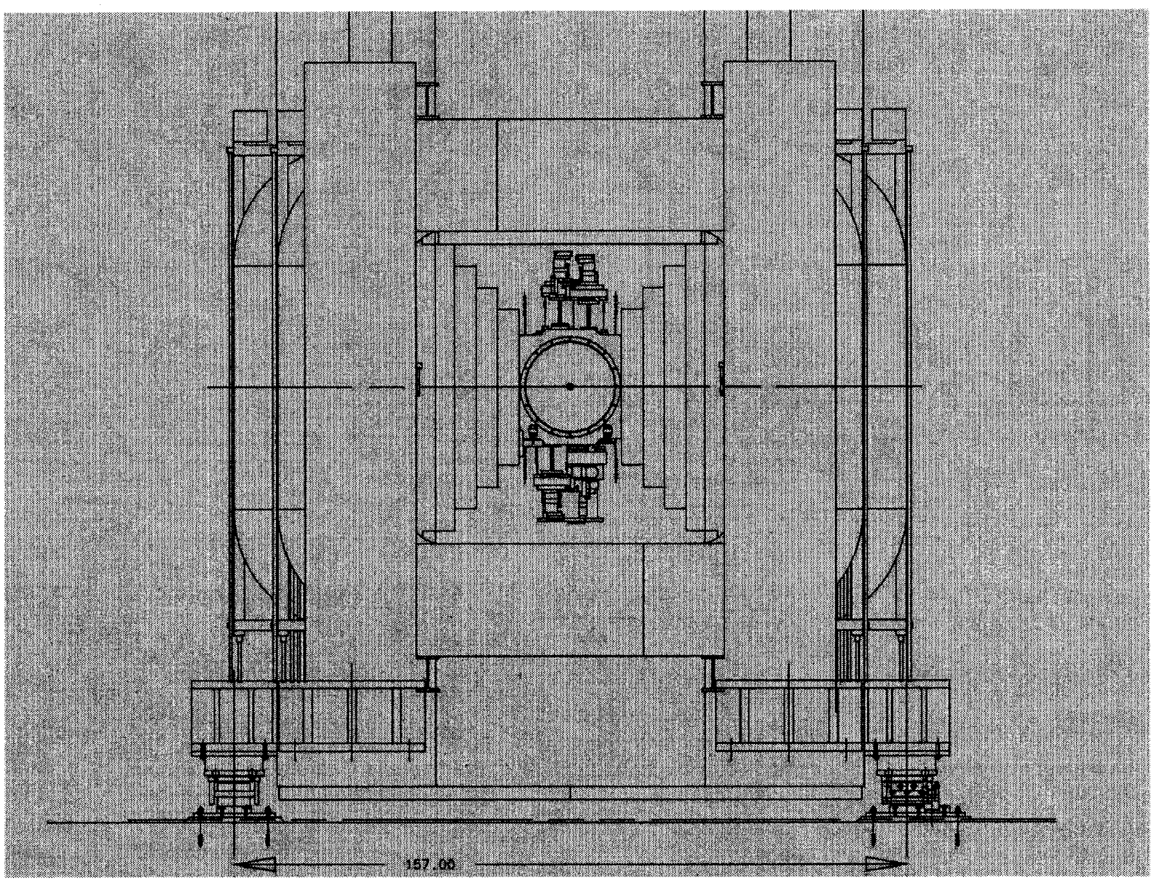

Figure 2: Partial side elevation view of the Vertex Magnet with moving rollers and Rail system.

Figure 3 on page 3 is a force distribute diagram based on the input from Figure 1 & 2, it is also necessary to make some assumptions to simple the calculation:

Four rollers will equally to take mass weight of the magnet, the locations of the rail to support (to contact?) the rollers are defined as A, B, C & D respectively.

It is assuming that the two plates of the rail are rigidly to connect together both on xy & zy plane.

The coefficient of friction in the rolling direction between roller and the top surface of

the rail is $f_r = 0.10$. so:
$F_{ay} = F_{by} = F_{cy} = F_{dy} = F_y / 4 = 112.50$ tons

Where: $F_y = 450$ tons, the mass weight of the Vertex Magnet,
F_{ay}, F_{by}, F_{cy} & F_{dy} are the vertical force to point A, B, C & D.

The lateral force caused by the allowable skew angle (+/- 0.02°) will not discuss in this section (It is also negligible to compare the lateral force F_{ax} or F_{bx}).

$F_{az} = F_{bz} = F_{cz} = F_{dz} = f_r \cdot F_{ay} = 11.25$ tons
Where, F_{az}, F_{bz}, F_{cz} & F_{dz} are the rolling forces subject to point A,B,C & D.

So:
$F_z = F_{az} + F_{bz} + F_{cz} + F_{dz} = 45$ tons

$F_{ax} = F_{bx}$

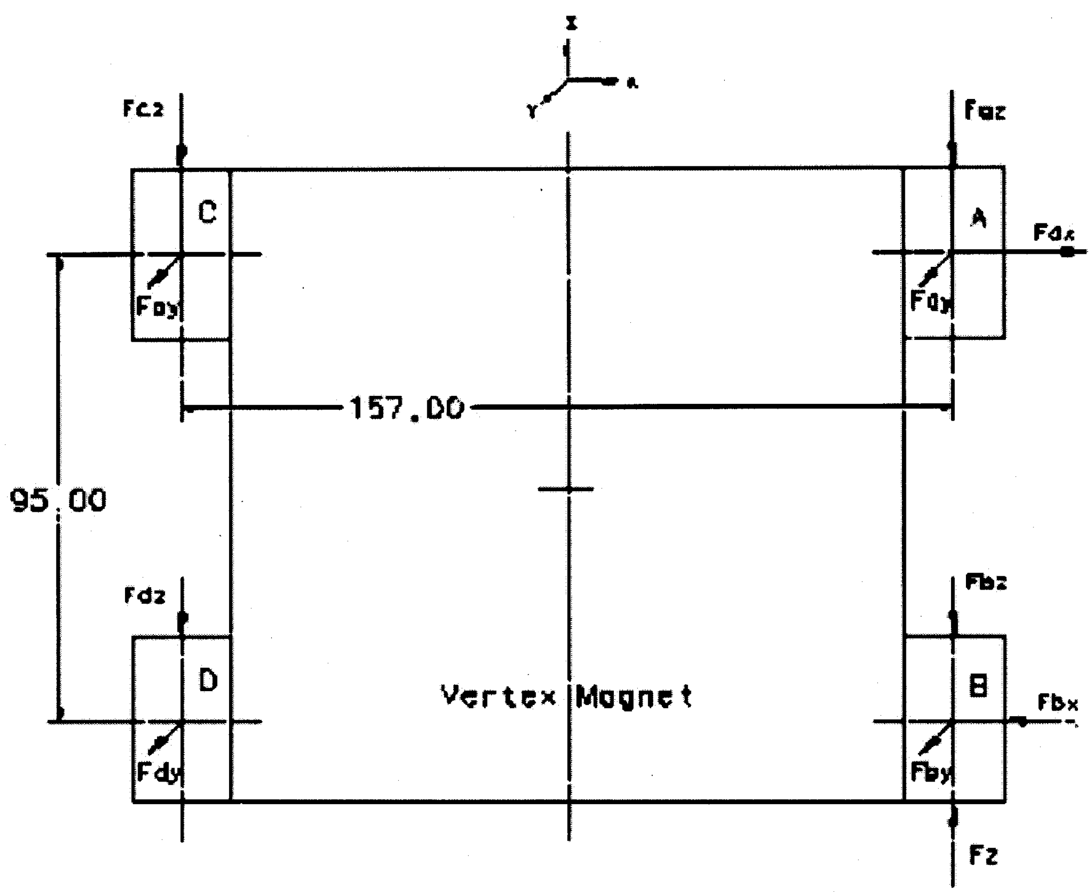

Figure 3. Force distribution of the VM rail system with only one drive force

For location B, where:

$\sum M_{By} = 0,$

So:

$$(F_{cz} + F_{dz}) \text{ x } 157.0 = F_{ax} \text{ x } 95$$

$$F_{ax} = [(F_{cz} + F_{dz}) \text{ x } 157.0] \div 95.0 = [(11.25 + 11.25) \text{ ton x } 157.0 \text{ in}] \div 95.0 \text{ in}$$
$$= 37.2 \text{ tons } = F_{bx}$$

The resultant shear load of the location A or B is:

$$F_{rsa} = F_{rsb} = (F_{ax}^{2} + F_{az}^{2})^{1/2} = 38.9 \text{ tons } = 77{,}800 \text{ lbs } (1)$$

It is also necessary to find the tensile force of the location A or B of figure 3.

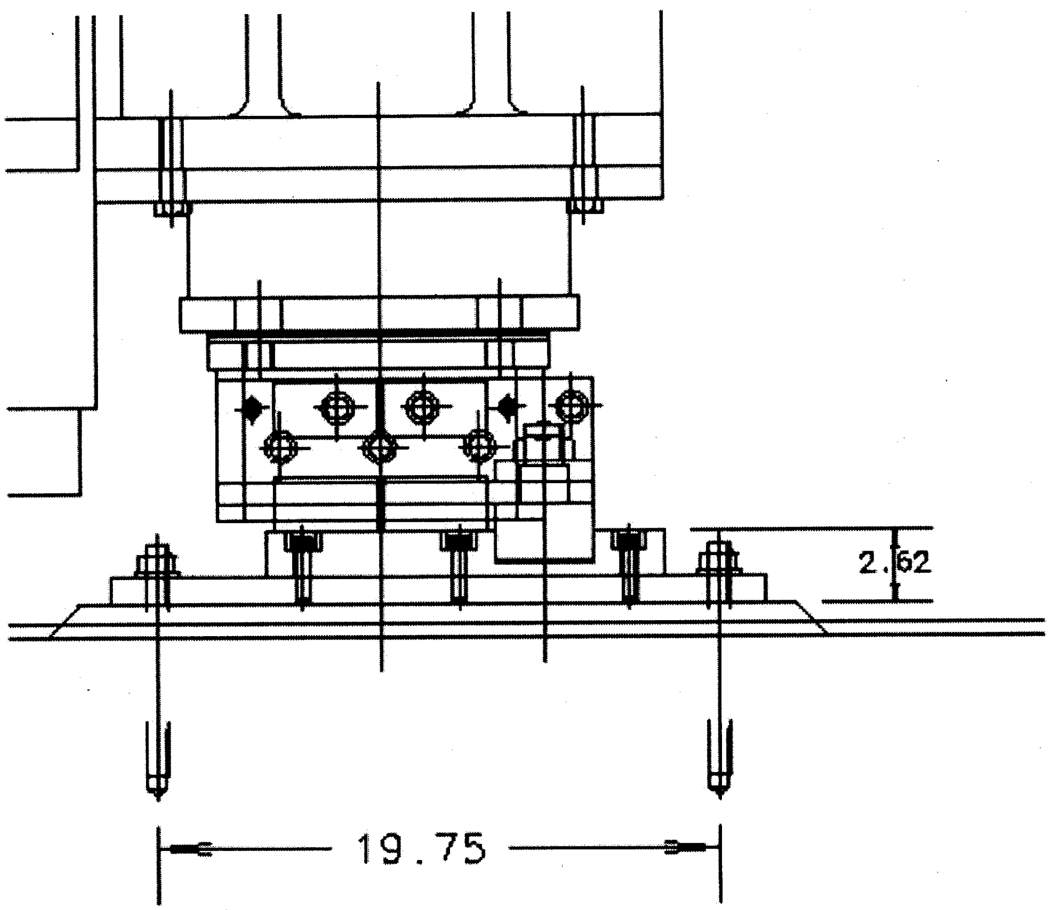

Figure 4: The enlarge xy view of location A or B of figure 3.

From Figure 3 & Figure 4, it is found that:

F_{ax} x 2.625 in = F_{ay1} x 19.75 in
F_{ay1} = (F_{ax} x 2.625 in) / 19.75 in
= 4.95 tons

Where: F_{ay1} is the tensional force of the one side of the anchor bolts subject to the shear force F_{ax} @ location A.

From Figure 3 and Figure 5, it is found that:

F_{az} x 2.625 in = f_{ay2} x 9.75 in
F_{ay2} = (F_{az} x 2.625 in) / 9.75 in
= 3.03 tons

Where: F_{ay2} is the tensional force of the one side anchor bolts subject to the shear force F_{az} @ location A.

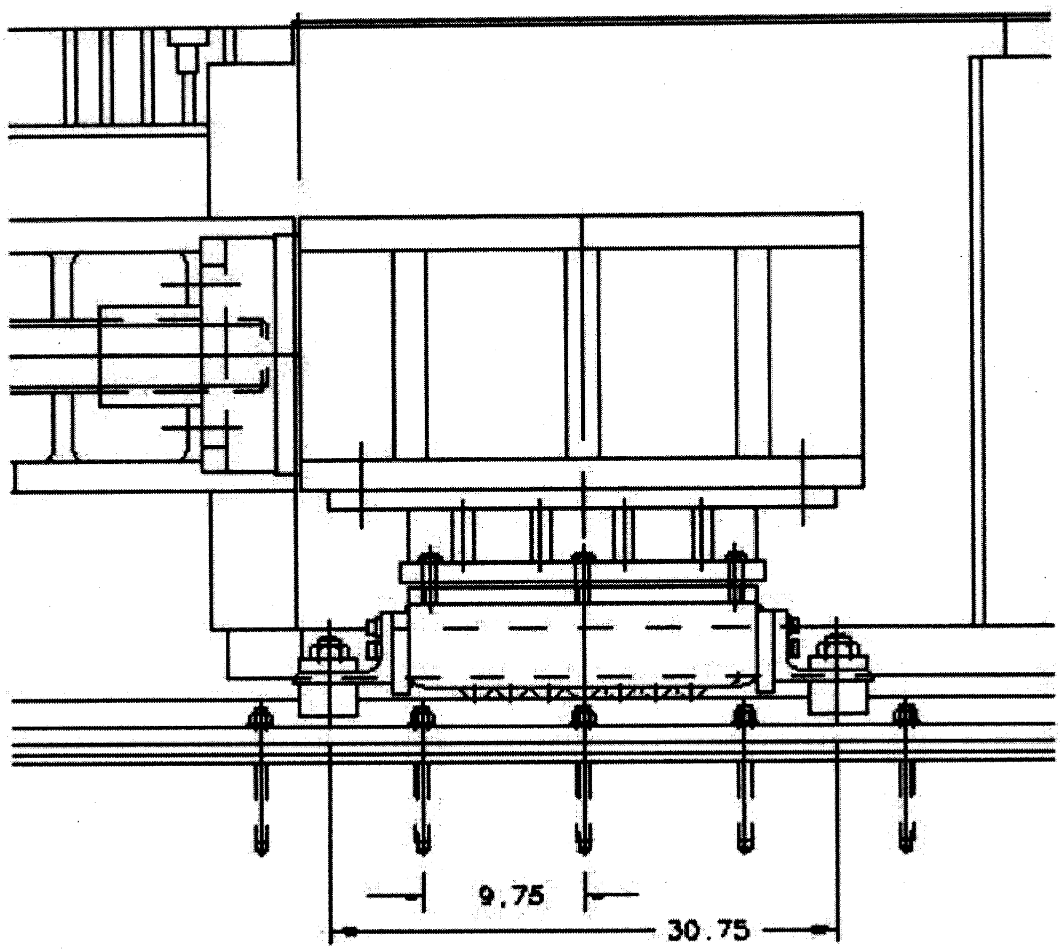

Figure 5: The enlarge zy view of location A or B of figure 3.

The resultant tensional force for one side of the anchor bolts:

$$F_{ay} = F_{by} = (F_{ay1}{}^2 + F_{ay2}{}^2)^{1/2} = \ 5.8 \text{ tons} = 11{,}600 \text{ lbs (2)}$$

The discussion of the anchor bolt applying to the rail system:

It is assuming that the anchoring design is based on the design criteria of the "HILTI Product Technical Guide", 2002 edition; and ASD 9th edition:

Per Figures 4 & 5, it is assuming there are number of anchor bolts within 30.75" (z dir.) force applying area to each side of the roller.

If using Carbon Steel Kwik Bolt II in concrete (3,000 psi), for ¾" bolt dia. With embedment depth 4.75", the allowable loads are:

$F_t = 4{,}130$ lbs

F_t: allowable load in tension

$F_v = 5{,}120$ lbs

F_v: allowable load in shear

(Per page 156, section 4.3.3 of HILTI Product Technical Guide, 2002 edition)

Per eq. (1) of page 4, and figures 4 & 5, it is found that the working shear load per bolt:

$$f_v = F_{rsa}/ 10 = 77{,}800^{\#} / 10 = \underline{7{,}780^{\#} > F_v\ (5{,}120^{\#})}$$

Per eq. (2) of page 6, and figure 4 & 5, it is found that the working tensional load per bolt:

$$f_t = F_{ay} / 5 = 11{,}600^{\#} / 5 = 2{,}320^{\#} < Ft\ (4{,}130^{\#})$$

Since the space distance 9.75" > S_{cr} (9.50"), it can be assuming that:

Recommended working tensional load $F_{rect} = F_t$
Recommended working shear load $F_{recs} = F_v$

To check the combined loading by formula:

$$(f_t/F_t)^{5/3} + (f_v/F_v)^{5/3} \le 1.0$$

(per Section 4.1.3 of HILTI Product Technical Guide, 2002 edition)

$$(2300/4130)^{5/3} + (7780/5120)^{5/3} = 0.376 + 2.009 = \underline{2.385 > 1.0}$$

Both $\mathbf{f_v}$ and the **combined load** don't meet the design spec. under current design assumptions.

If choose 1" dia. Anchor bolt:

Since the min. space dist. S_{cr} for 1" dia. Bolt * will be 12.0", then it will be 4 anchor bolts instead of 5 anchor bolts for each effect side (See figure 5), so the working shear load for each anchor bolt will be:

f_v (1" dia.) = 77,800# / 8 = $\underline{9{,}725^{\#} > 9{,}200^{\#}}$

1" anchor bolt is not available for some anchors.

Conclusions:

Under the current design assumptions, the applying working load (shear) **will be larger** than the designated allowable shear load of HILTI anchor bolt (3/4" & 1" dia.) when VM track-moving system is driven by one side force only.

However, the results will be changed by:

The coefficient of friction is not as it was assumed as $f_r = 0.10$ (the most important factor).
The friction force between top surface of the rail and the roller in x direction is lesser than F_{ax} or F_{bx} (i.e: the VM rotating along y axis).
The change of the distance between two rollers in z or x direction.

References:

1. "Product Technical Guide", HILTI North America, 2002 edition
2. "ASD" 9th edition, AISC.